MODELING OF OPENCAST MINES USING SURPAC AND ITS OPTIMIZATION

A THESIS IS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

MINING ENGINEERING

By

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National Institute of Technology

Rourkela – 769008, India

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CERTIFICATE

This is certify that the thesis entitled **"Modeling of opencast mines using Surpac and its optimization"** submitted by **Mr. Harshit Agrawal (Roll No-108MN048)** in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Mining Engineering at Nationa Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/ Institute for award of any Degree.

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ABSTRACT

In this developing world, the demand for raw materials is increasing at a steady rate, in order to bridge the gap between supply and demand, technological advancement and automation in production method is needed. Since the raw materials are non-replenishable in nature and have took millions of years in their formation, so these resources should be judiciously used with maximum extraction level and aiming for zero mining waste, while adhering to all safety and regulatory norms.

In this project, an effort have been made to estimate the resource using Surpac software for ore modeling and optimization algorithm are used for optimizing the shape of the pit and in ultimate pit design to ensure maximum extraction of the deposit.

If the available mineral resources are not properly utilized then the cost of production will increase and hence company may lose in this competitive environment. So to ensure that efficient utilization of available resources in terms of shovels and dumpers and other face machinery available, a C++ program have been developed which can dynamically allocate the dumper to the nearest available shovel obeying various constraints to ensure that the production target is reached and the process is fully optimized.

Keywords: Modeling of deposit, Open Pit optimization, Ant colony optimization.

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CHAPTER- 1

INTRODUCTION

1.0 Introduction

The magnanimous growth and ever increasing demand of finished products have pressurized the mother industry (mining) to supply raw materials to meet the increased demand for growth and sustainable development of the society. These materials can be extracted from the earth crust by any of the two methods of mining i.e., surface mining methods and underground mining methods. Surface mining operations can be classified into open pit, opencast, strip, alluvial and in-situ mining, depending on method of mining being considered (Hartman, 1987). Open-pit mining is a method of developing and exploiting the deposit by making a void in the surface, also known as pit and developing it sequentially to extract the ores. It starts off with a small pit and gradually develops with the lapse of time in a pre-planned manner to take the final shape of pit called as ultimate pit which includes the initial void by which the deposit was attacked. Opencast mining is the advancement in the open pit mining methods, developed due to the acute shortage of granted lease hold area where the overburden can be piled for future reclamation purposes. In open-cast mining method, after all the ores in a particular area have been mined the overburden materials are dumped in-pit in those extracted area instead of dumping it in overburden pile within the lease hold area outside the pit. This has proved to be cost effective and acquires lesser land area and continuous reclamation work is also ensured. At present opencast mining has larger share of total ore production in India, owing to the technological advancement due to availability of heavy earth moving machines (HEMMs) which has increased the rate of production while ensuring safety and requires lesser manpower. The increased rate of operation facilitates lesser development time.

1.1 Problems in pit optimization

Opencast mine planning is a multi-parameter optimization problem which requires simultaneous solution (Sevim & Lei, 1998). The parameters involved in open pit production planning are inter-related hence if one parameter is affected it affects all other related parameters, so without ascertaining the value of one parameter the next parameter cannot be ascertained (Figure 1). Mine life is determined as the probable time required to mine all pits present in ultimate pit limit (UPL) design, in a proper sequence in order to ensure maximum profit. In order to maximize profit, a cut-off grade is determined based on factors like, market price of finished metal/processed ore, mining and processing cost, overhead charges like royalty, compensation, etc. Cut-off grade must be fixed during planning stage as it will be the driving factor in determining block economic value (BEVs), based on the BEVs ultimate pit is determined making use of various graph closure algorithms available like minimum cut algorithm, and subsequently production schedule is developed by analyzing various pushback designs in order to optimize the sequence by hit and trial method keeping in mind annual targets to be achieved, final mining sequence is one which give maximum economic return subjected to all operational constraints (Sevim & Lei, 1998).

1.2 Significance of project

Manual method of open pit mine planning and design require tedious work by planning team in order to define ore boundaries, defining mine configurations in sections based on available economic and technical information. This method was labor intensive, prone to error and time consuming, moreover it cannot be applied to large open pit mines with millions of blocks. Hence, it was one of the most important topics for researchers.

Last 40 years have seen a tremendous advancement in the field of computer application and numerical modeling and its increased use in mining industry. With the evolvement of new software's incorporating geostatistics based modeling of pit like solid modeling, 3D block modeling, etc. and development of various optimization algorithm like branch and bound algorithm, minimum cut algorithm, and the most widely used Lerchs- Grossmann 3D algorithm (Lerchs & Grossmann, 1965) have helped mine planners in developing mine plans which are accurate and reliable. Benefit of using these algorithms are that they are simple to formulate and use, requires lesser computational time and are user friendly, i.e. they can be customized as per users need and can incorporate real time complexities like mining constraints, working slope angle, time value of money, etc. (Dowd & Onur, 1993). With the advancements in optimization algorithms even low grade deposits can be mined successfully which earlier was not possible.

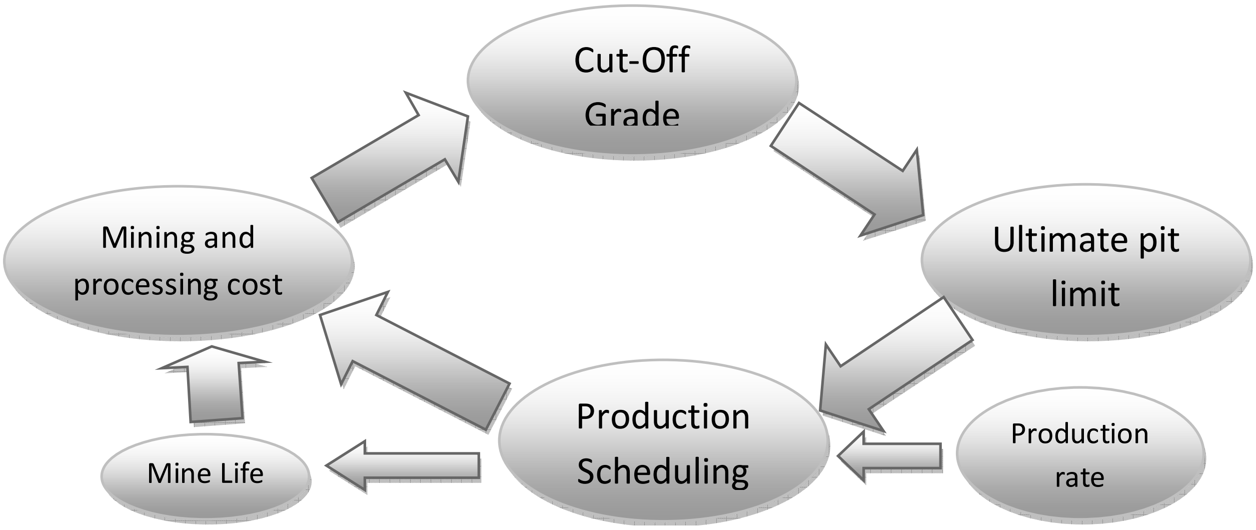

Figure 1: Inter-relationship of multiple parameters involved in open pit optimization (Sevim & Lei 1998).

1.3 Scope of work

With the gradual technological developments mining industry is seeking for automation of their operations in order to meet the increased demand from society. The project aims at providing an insight of how software's can be helpful in reserve determination and can be beneficial in real time mine planning and production scheduling. Use of software have made calculations easy for various parameters like calculations related to life of the mine, production planning, long term and short term planning, etc. This can be helpful to top management people as resources can be easily modeled and are easy to view and analyze and hence steps can be taken for ensuring steady production.

1.4 Objective of project

In recent years, mining industry has undergone wide scale mechanization in order to ensure higher production while ensuring safety of its workers and to meet long term production goal at sustainable rate. Proper planning of reserve based on mathematical analysis of available data is need of the hour. The fleet deployed should be optimally used in order to minimize operating and mining cost and to meet production target. With evolvement of computer software and optimization algorithms, mining industry are seeking the analysis done by these software to plan their mine in most optimized and accurate way to compete with global players.

The objective of the project is to model the deposit using Surpac and provide the pit optimization sequence by generation of a number of time dependent push back design. It also aims at developing a C++ program which will facilitate dynamic dumper allocations to shovels based on real time monitoring data being continuously fed to the program. It aims at reducing idle time of both shovels and dumpers and would facilitate the achievement of target of production while being cost competitive.

CHAPTER-2

LITERATURE REVIEW

2.0 Introduction

An extensive literature review was carried out to find various approaches which researchers have used in past in field of open pit optimization and automation in truck dispatch system. In this thesis, developments in the field of Ant colony optimization for truck allocation have been widely reviewed.

Mueller 1977, proposed a model based on dispatcher which keep track of the status and position of the equipment in the pit and guides the decision making process. The main components of the dispatcher are shovels and dumpers which are represented by a block. The decision for dispatching the dumper is taken once it has dumped its load either in dump site or in crusher plant. The dispatcher updates the value and calculates various response functions to allocate its new assignment.

Wilke & Reimer 1977, proposed a linear programming model for short term production scheduling for an iron ore mines.

Jordi & Currin 1979, proposed a model to optimize Net present Value (NPV), net profit and production output.

Zhang et al. 1986, proposed a new method of optimization that combined inventory theory, dynamic programming, computer simulation involving interactive technique to calculate production scheduling of an open pit mines.

Dagdelen & Johnson 1986, developed application of Lagrangian parameterization for optimizing production planning. This method involved use of ultimate pit limit algorithms in order to generate block models having different block economic values to develop production schedules.

Whittle 1990, has done extensive work using meta-heuristic approach and have developed an algorithm which is most widely used throughout for open pit optimization.

Achireko & Frimpong 1996, proposed an algorithm which can utilize the random field properties associated with grade of ore, product price, etc. They used artificial neural network to classify blocks into classes on the basis of their conditioned value after modeling block characteristic using conditional simulation. Error back propagation algorithm was then used to optimize the ultimate pit limit by minimizing desired errors in multiplayer perception under pit wall slope constraints.

Sevim & Lei 1998, developed a method which had the capability to determine cut-off grade, mining and processing rate, mining sequence, mine life and the ultimate pit limit design.

Ramazan & Dagdelen 1998, proposed a new algorithm which has the capability to develop push backs of minimum stripping ratios.

Ronson 2001, has done an extensive study on various software available for open pit mine planning and scheduling. He had made an attempt in outlining the various modules available for particular work and had also made a comparative study on which module of particular software is user friendly and easy to learn and the accuracy of results obtained from them. A detailed review of mining softwares is available like, Minex, Vulcan, Surpac, Datamine, etc.

Bissiri 2003, have tried to simulate the social insect model like ant colony system into mining problem and have made an analogy between the two processes. He had tried to formulate an agent based truck dispatch system based on ant colony optimization in which he had calculated stimulus of shovels, threshold of dumpers and response value of shovels for a particular dumper to facilitate real time allocation of dumpers to shovels in day-to-day planning and production scheduling in order to meet the target.

Dorigo et. al. 2004, in his on Ant colony optimization has provided an analogy between real ant colony and artificial ants (shovel-dumper combination) and minimum cost path and provides a metaheuristic approach to ant colony based optimization. They have also shown its application in vehicle routing problem and in scheduling problems.

Ramazan et al. 2005, proposed a new production scheduling optimization technique based on fundamental tree algorithm while making an attempt to decrease the number of integer variable and solve problem as a mathematical programming model.

Sattarvand & Delius 2008, in their paper have made an effort to bring up the various meta-heuristic optimization methods in open pit production planning and have shown how ant colony optimization can be used for optimizing the production planning.

CHAPTER- 3

METHODOLOGY

3.0 Introduction

In open pit mining operation blocks of earth are dug from surface in order to extract the ore. During mining, land is excavated forming pits which increase gradually until mining process if over. The final shape of this pit is determined during planning stage itself. In order to optimize the ultimate pit to maximize profit whole area is divided into 3 dimensional blocks of equal size, the drill hole information regarding the assay value, grade of ore, etc. is ascertained by various geo-statistical method applied on borehole information's and ore in each block is estimated. The mining cost, processing cost, and other miscellaneous costs are taken into account while deciding the block economic parameter and hence the block economic value. The optimal pit is designed to maximize the total profit while adhering to safe working conditions like safe slope angles, and other constraints like a block can be mined only when blocks on top of it are mined. In general 45^{o} slope angle is maintained which can be depicted in 3D view as represented in Figure 2.

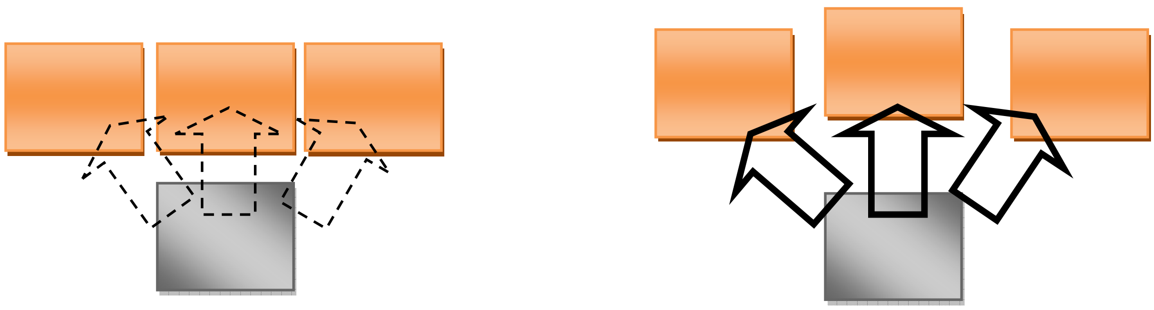

Figure2: Blocks to be removed to maintain slope angle and pit shape.

In order to remove the lower blocks three top blocks are to be removed. The group of block falls in pit limit design only if the sum of block economic values of all the blocks i.e., 3 waste blocks and one ore block is more than 0, i.e. extraction of the block is profitable, otherwise these set of blocks are not included in the ultimate pit design as if these blocks are mined then the overall profit will decrease (Hustrulid & Kutcha, 1995).

Open cast mine planning is done by developing the block models and then dividing the deposit into smaller pits which contain both ore and waste blocks which are to be mined in order to reach the pit limit and these operations are done keeping in mind the overall optimization of the pit and reaching ultimate pit limit design. A 3D block model gives the information about the surrounding blocks and the overall economy in extracting a set of blocks. The pit size can be small or large containing millions of blocks, the average grade of each block is estimated using geo-statistical approaches and prevailing site conditions (Sevim & Lei, 1998).

The development takes place in a number of phases and has different pit layout in each phases, these sequence of pits for timely extraction of deposit is called as push back designs. The mining operations in each phase of push backs are scheduled to start from top surface and extract materials on top layer before extracting the lower deposits in order to maintain the pit slope angles and pit geometry (Sevim & Lei, 1998). These push backs forms the short term production planning while nesting them leads to the long term planning. The main objective of pit optimization is to find the sequence in which maximum extraction of ore is possible. These results are used to decide short term production planning and then developing daily, weekly, monthly, quarterly, half-yearly and yearly production plans.

The project has three separate stages, these are:

1. Modeling of deposit using Surpac,
2. Optimization of deposit using minimum cut algorithm in Matlab and
3. Dynamic truck dispatch system using ant colony algorithm based program.

3.1 Stage 1: Modeling using Surpac

Surpac is an complete mine planning software which has various modules ranging from drilling and blasting, surveying, pit design, geo-statistics and grade control, block modeling, solid modeling, open pit design, underground design, etc. The beauty of Surpac is its user friendliness; it can be fully customized based on the customers need. Moreover, it is highly flexible as the values generate in Surpac can be used in a variety of other software's. Some of these modules have been use for reserve determination and modeling of the deposit.

From the data available with the exploration team, a geological database is created to determine the extent of ore deposit and its basic geo-statistical characteristics. The borehole data are composited in order to use it to find geo-statistical values of the deposit. The boreholes are displayed on the basis of the collar values taking into account the coordinates of each and every borehole present in the database. Once the geological database is created, total volume of reserve can be estimated by developing solid model comprising of all these borehole data. In order to obtain the solid model the borehole present in the database are sectioned at regular interval and the strings are stitched together to form solid model. The solid model so developed is then fitted into a block model of regular size developed to generate a constraint block model. The block economic parameter is then calculated using ordinary kriging method, based on the grade of each block.

Operating layout is the key element in production scheduling, and is developed keeping in mind various constraint of mine design. This aims at determining the rate of advance of different faces so as to achieve a steady state production. The sequential mine design or push backs are designed based on long term production planning. Production planning and scheduling provides an estimate of progress of mining operations. Production planning is divided into three basic stages i.e. Long term planning, medium term planning and short term planning. Long term planning aims at maximizing the net present value of the total profit from production process while satisfying operational constraints like working slope angle, grade blending, ore production, processing constraints, etc. it acts as a guide for medium and short range production planning. One of the main aspects of long term production planning is to maintain steady state production with target achievement. In order to achieve long term planning goal, it is further divided into medium and short range planning, these medium and short range planning are an indicator of the achievement of overall target.

The planning starts with the divide and conquering policy in which the entire deposit is divided into pit of smaller sizes so that it is easy to manage operations in such individual pits. These small pits are called as sequences, or push backs. Phase planning starts with the commencement of planning after ore body have been modeled so that such area should be sequenced first which give maximum cash flow i.e. area with low stripping ratio, while successive sequences can be made on basis of cash flow contributed by them ultimately reaching the ultimate pit shape (Mathieson, 1982). The extraction ratio proceeds from phase or sequence having highest average profit ratio (APR) to the lowest.

$$\boldsymbol{Average\ Profit\ ratio = \frac{Revenue}{All\ costs\ incurred}}$$

Some basic steps have been enumerated by Crawford(1989a) for push back design, these are:

1. Start with ultimate pit design: this include development of detailed data of ore grade and stripping ratio distributions for different cutoff grades in the designed pit limits.
2. Planning is largely motivated by maximizing the net present value (NPV) and provides stable cash flow.

3. Operating design for developing push back include information on bench widths, road widths(depending on size of equipments), slope angles, overall operating slope, bench heights , etc.

3.2 Stage 2: Optimization using minimum cut algorithm

There are a number of algorithms available nowadays for open pit optimization based on linear programming and on graph theory. From the plethora I have used the minimum cut algorithm based on graph theory to calculate the maximum graph closure, i.e., maximum flow or minimum cut to optimize the pit shape.

3.2.1 Minimum cut algorithm

The pit design problem can be represented using a directed graph, G= (V, A), where V gives set of nodes and A gives set of directed arcs. A node is represented as a block and the node is assigned weights representing its block economic value (BEV). A directed arc is made from node i to node j, if block i cannot be extracted before block j lying on layer above block i. In order to maximize the profit by extracting the blocks, a set of nodes are chosen in the graph which provide maximum profit, such that all successor nodes are also included in the set. Such a set is called maximum closure of the graph G.

In formulating open pit mining operation in minimum cut algorithm, each block is represented as a node in graph and the slope requirements are represented by precedence relationships represented by set of arcs A in the graph. The integer programming formulation reveals the minimum cut structure. In the maximum flow problem directed network with capacity u_{ij} on the arcs is considered. In addition to these two nodes one source node S and another sink node T are also specified. The objective function being to find maximum flow between source and sink while satisfying arc capacity constraints. Consider x_{ij} represents flow on arc (i, j), and A represents the set of arcs in the graph, the maximum flow problem can be formulated as:

$$\textbf{Maximize } P = \Sigma\, w_j * x_j$$

$$\textbf{Subject to: } x_j - x_i \geq 0; \quad \forall (i,j) \in A. \textit{ and } x_j \in [0,j]$$

Where, x_i is the binary variable with value 1 if it is present in the graph closure and 0 if it is outside the graph closure, and w_j is the weight of the node depending on the block economic value of that particular node. Picard proved that maximum-closure problems are reducible to minimum cut problems it is possible to apply efficient maximum flow algorithm to calculate the values. One such algorithm is Ford Fulkerson algorithm. The following pseudo code is used for Ford-Fulkerson algorithm (Ford & Fulkerson, 1957).

Pseudocode:
f: flow;
G_f: the residual graph with respect to the flow;
P_{st}: a path from s to t;
U_{ij} : capacity of arc from i to j.
Initialize $f = 0$
If $\exists P_{st} \in G_f$ do
find $\delta = \min (i,j)$□$P_{st}U_{ij}$
$f_{ij} = f_{ij} + \delta \;\; \forall (i, j) \in P_{st}$ else stop f is max flow.

Detailed description:

1. The algorithm starts with a feasible flow,
2. A residual graph is constructed G_f with respect to the flow,
3. The path is searched by doing breadth-first search from s (a positive capacity is referenced to adjacent nodes in the graph) and observing if the set of s- reachable nodes contains t. if S contains t then there is a path and then the flow in the path can be increased. Hence the flow in the arc can be increased by the minimum flow capacity of the arcs present in that path,

4. Update the residual graph by updating the flow capacities of forward arcs by the difference between current capacity and value of flow on that path and updating reverse arcs value by sum of the current capacities,
5. Go back to step 3,
6. If S doesn't contain T, then flow is maximum, so stop.

3.3 Stage 3: Dynamic truck dispatch algorithm based on Ant colony optimization

When an ant travels from nest to food location it leaves a pheromone trail on the ground which increases the probability that other ants will follow the same path. When the ant meets with a threat in the path they swarm in every possible direction to reach to the food source. The pheromone intensity increases in those areas where more movement of ant is present i.e. the shortest path and gradually the pheromone in the longer path evaporates and all ants try to move through the same shortest path. The movement of ant away from the line is of great significance as those ants can find a path better than the current optimum path and thus in similar manner the pheromone trail in that path will also increase its intensity by repetitive movement of that ant through that path. Since that path is the shortest path so by the time another ant by some other path will reach the food source the ant travelling through the shortest path will leave the food source. In short the number of trips made by ant through shortest path will be more as compared to any other path, this will increase the pheromone concentration in the shortest path, and the ants will gradually start following this path thus optimizing their capacity. This analogy has been taken for real time monitoring and dispatch of dumpers in open pit mining operation. Initially dumpers are allotted to shovels present at the face in accordance with the short term planning, but in case of breakdown of shovels or dumpers, this set up is disturbed so dynamic allocation is needed to optimize the production. It may happen that during a period ore production is more necessary as compared to waste production, so during that time, dumpers initially allocated to waste block can be re-allocated to ore block in order to meet the production target and vice-versa. Based on the analogy, the behavior ants adopt when faced with threat (Wilson, 1984) can be applied to dispatching dumpers to shovels in open pit mining operations.

1. The model is generated is based on long term plan imposed by grade distribution of ore body, sequence of blocks to be mined during that time frame, demand of shovels by the blocks to carry out the production at specified rates.
2. Once shovels are assigned to the blocks, a number of trucks is allocated to each shovels based on stripping ratio to be followed.
3. Once dumpers are allocated to the shovels they are dispatched in a way that the number of trucks initially allocated to each shovels remain unchanged until breakdown occurs. On occurrence of break downs the dispatcher allocates or re-allocates the dumpers to minimize the impacts of breakdown on the entire system.

3.3.1 Ant colony optimization

Sattarvand 2009, has made an attempt of using ant colony optimization in optimizing long term open pit mine production planning. The process has the ability to optimize ultimate pit and long term production planning simultaneously by optimizing multi-parameters of mine schedule problems. Bissiri et al. 2003, have made an attempt to find an analogy between works done by ants in colony and opencast mining operations. This can be demonstrated in Figure 3.

From Figure 3 it can be seen that foraging activity is being compared to mining of ore from the block, as during foraging, ants search for food in their surrounding and once a food is found they bring them back to their nest, in a similar way as ore blocks are searched for ore in the available area and once an ore block is detected it is extracted and sent via dumpers to dump site or crusher plant depending on the cut-off grade and considering other operating parameters.

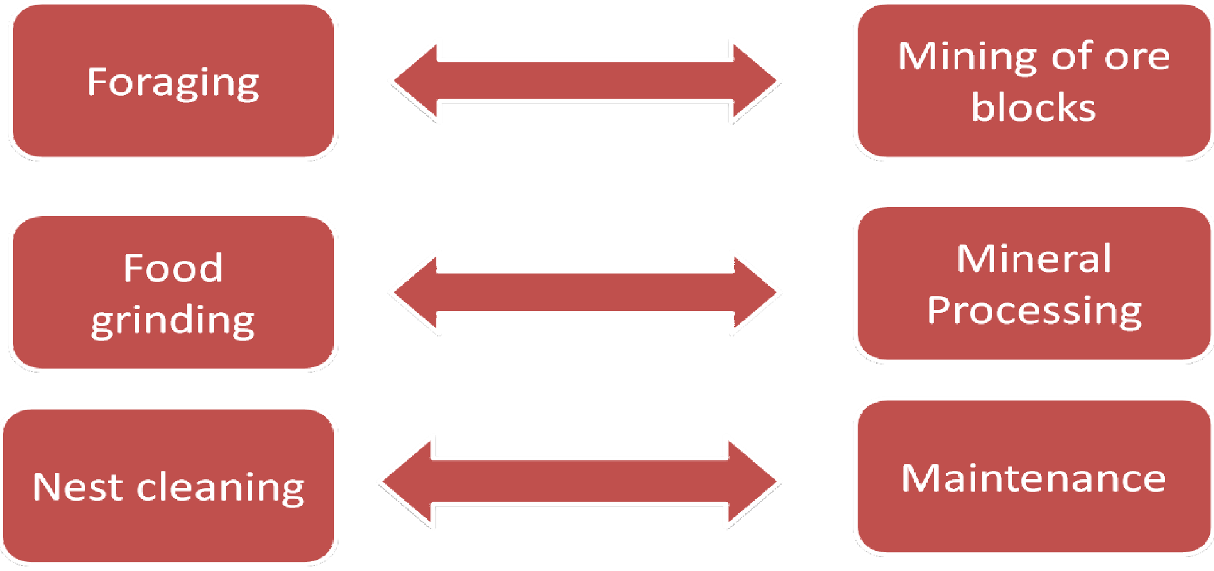

Figure 3: Analogy between ant colony behavior and open pit mining (Bissiri et al, 2003)

The next analogy of food grinding action with mineral processing operations relate with each other, as ant grinds their food swarmed by the fellow ants to take the nutrients to be served to the population of the colony, in a similar way, the processing plants crushes the input ore, cleans them and beneficiates them to be used for other purposes.

The next analogy of nest cleaning with maintenance can be related as ants clean their nest by removing dead ants and other wastes from the nest in a similar way, wastes are removed from the processing plant and send to tailing ponds and the removed of dead ants can take analogy from maintenance of break down equipments in the maintenance shop to be able to work again.

3.3.2 Vehicle Routing Problem using Ant colony optimization

Ant colony optimization has been successfully implemented in several combinatorial optimization problems like vehicle routing problem, travelling salesman problem. Vehicle routing problems has many variants like vehicle routing problems with time windows, time dependent vehicle routing problems, dynamic vehicle routing problems, etc. (Rizzoli et al., 2005). Dynamic Vehicle routing problems incorporate those conditions when customers order arrives while previous order is under process. It is applied when the service requests are not completely known before the start of the service, rather the request arrives during the distribution process, this is called dynamic vehicle routing problem. As new orders arrive, the routes are dynamically changed and are re-planned at dispatching time in order to include the new requests/orders. Application of ant colony optimization in vehicle routing problems is demonstrated with an example:

Consider a service company providing Cab facility in a metropolitan city. Let us assume that communication between office and cab drivers exists and the location of cab drivers are continuously been updated at the office. Owing to dynamic vehicle routing, the operator in office can communicate to the driver about his next passenger's location, in such a way that the driver reaches the destination in shortest possible time. In this process driver know just his immediate task and is not clear about his next assignments. The dynamic vehicle routing system has information collection point which collects the information about the various assignment and allocates the best possible solution to the task. i.e. nearest driver is sent to that location, to provide fast service and ensuring optimum use of available resources by minimizing idle time of each cab (Gendreau & Potvin, 1998).

Bissiri 2003, had made an attempt in generating a response function that is dependent on the shovel stimulus to particular dumper, ability of dumper to respond to shovel and status of dumper, whether empty or loaded. The response function r_{ij} can be expressed as:

$$r_{ij} = \frac{(S_i(t))^n}{(S_i(t))^n + (\theta_{ij}(t))^n} \; X \; status_j(t), \; 1 \leq i \leq N \text{ and } 1 \leq j \leq M. \qquad (1)$$

where,

Si(t) = demand of shovel I for dumpers

Θij(t) = ability of dumper j to respond to the demand of shovel i,

N = total number of shovels during operations at faces

M = total number of dumpers in operation.

n>1 = steepness of stimulus and threshold.

Status j(t) = $\begin{cases} 1, if\ dumper\ is\ empty \\ 0, if\ dumper\ is\ loaded \end{cases} = load\ status\ of\ dumper\ j,$

The threshold function Θ of dumper is dependent on dumper carrying capacity, instantaneous distance to shovel, previous allocated shovel and road conditions. The road conditions have impact on time the dumper will take to reach to the shovel at face form the dump site or crusher plant location. The road condition varies between 0 and 1, o is assigned to highly undulating road and 1 to black pitched road in excellent condition.

Θ = f(truck capacity, distance to shovel, previous assignment, road conditions)

The shovel stimulus $S_i(t)$ is calculated as a function of deviation factor of shovel from current production, it also depends on the number of dumpers routed to the shovel i at time instant t, and queue length present at shovel i at that instant of time t. the shovel stimulus $S_i(t)$ is given as:

$$\mathbf{S_i(t)= k\ d_i(t)- q_i(t)- e_i(t),} \qquad \textbf{(2)}$$

where, k is the stabilizing factor whose purpose is to give weight to deviation factor of shovel.

The deviation factor $d_i(t)$ of shovel is a relation showing the deviation of shovel from the estimated production rate, which is supposed to be achieved by the shovel till time t at fixed rate of production, the deviation function is calculated as:

$$\mathbf{d_i(t)= \frac{\mathit{E(t)- T}}{\mathit{C}},} \qquad \textbf{(3)}$$

where,

E(t) is the expected production rate at the time deviation is calculated.

T is the actual production achieved till time t, C is the bucket capacity of the shovel.

The shovel stimulus is expressed in exponential form to et positive values. It can be represented as:

$$\mathbf{S_i(t) = exp[k.\ d_i(t)\text{-}q_i(t)\text{-}e_i(t)]} \qquad \mathbf{(4)}$$

The threshold function Θ_{ij} of dumper is dependent on dumper assignment factor $P_{ij}(t)$ whose value varies with the number of time a particular dumper has been allocated to a shovel i, the decision function $\varepsilon_{ij}(t)$ is calculated to incorporate road condition factor in order to make decision about allocation of dumper to shovel, and on the ratio of bucket capacity of shovel to dumper capacity in order to determine the number of passes and hence time taken by shovel to fill the dumper, it is calculated as per equation given below:

$$\mathbf{\Theta_{ij} = -P_{ij}(t) + \varepsilon_{ij}(t) + K} \qquad \mathbf{(5)}$$

Where,

$$P_{ij}(t) = \begin{cases} 1, if\ dumper\ j\ was\ assigned\ to\ shovel\ i\ for\ more\ than\ once \\ 0.5, if\ dumper\ j\ have\ been\ assigned\ to\ shovel\ i, atleast\ once \\ 0, if\ dumper\ j\ have\ never\ been\ assigned\ to\ shvoel\ i \end{cases}$$

$$\varepsilon ij\ (t) = \begin{cases} \alpha \frac{d_{ij}(t)}{d_i}, & dumper\ j\ is\ alloted\ to\ shovel\ i\ at\ the\ time\ of\ decision \\ 0, & otherwise \end{cases}$$

$$K = \frac{C_s^i}{C_d^j},$$

where

α is the road condition factor with value 0< α <1.

dij(t)= instantaneous distance between shovel and dumper

di = fixed distance between shovel and dump site or crusher plant.

C_s^i = bucket capacity of shovel i,

C_d^j = capacity of dumper j.

After calculation of these values the response function is calculated as given in $r_{ij}(t)$, dumper is allocated to the shovel with maximum response value.

CHAPTER- 4

CASE STUDY:

RESULTS AND DISCUSSIONS

4.0 Introduction

The study was carried out based on the borehole information available from an iron ore mine under the Steel Authority of India Limited (SAIL) at Barsua. The Barsua iron ore mine lie in the hills ranges of the iron ore series. It is 18 km long spread in north-south direction on the top of the hill as a narrow strip. The mine is easily approachable by two independent roads, one leading to northern end i.e. Kalta iron ore mine and other in southern end i.e. Barsua iron ore mines. The mine lease area is divided into three parts i.e. Barsua, Taldih and Kalta, of which the study have been carried out in Kalta region, between the Kalta iron ore mine and Barsua iron ore mines lies the Taldih deposit which is covered with thick Toda reserve forest so is not currently in operation. The figure 4 shows the location of Barsua- Taldih- Kalta deposit. The red circle shows the area under study.

According to the generally accepted concept, the iron ore body was formed by secondary process of leaching and enrichment of iron bearing rocks under certain structural and meteorological contro.ls. This process has also produced different ore types of varying physical, textural and chemical compositions. The ore body occurs as capping of various spread and thickness over several prominent hills, generally following strikes of country rocks. The ore body is bounded in west by continuous exposures of Banded Hematite Jasper (BHJ) while its eastern periphery is generally devoid of rock exposures and is covered with iron ore floats and talus. The ore body is lenticular in shape and extends over the Barsua- Taldih-Kalta region. The ore is generally harder at top and softer at depths. The irregularly laterised harder ore forms the crest of the ore body as per hill profile as thin mantle of 10- 20 m at Barsua to 8- 40m at Kalta.

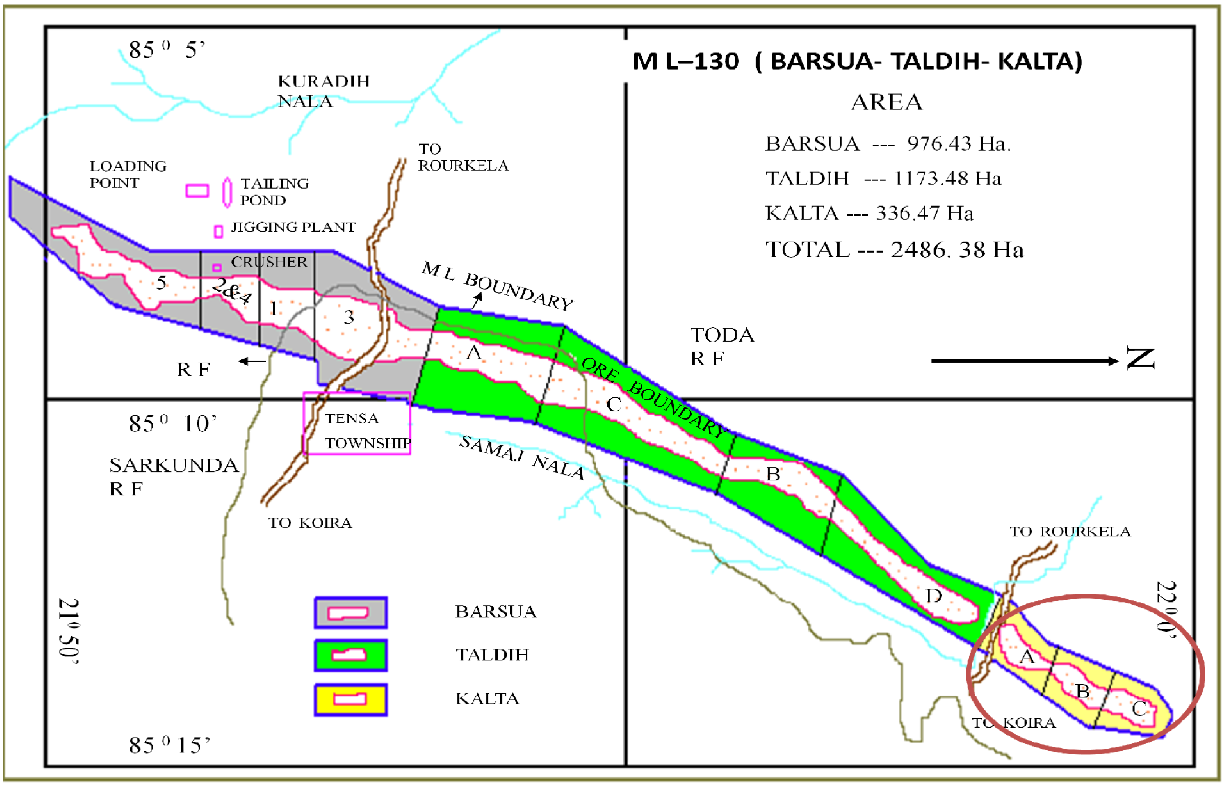

Figure 4: Lenticular shape iron ore deposit of SAIL Barsua- Taldih-Kalta
(**Source:** Survey department, Barsua iron ore mine)

4.1 Results and Discussions

The data available from mine has been modeled and C++ program have been developed for dynamic allocation of dumpers in real time scenario.

4.1.1 Modeling of deposit

Based on the borehole information available from the survey department of Barsua iron ore mine office, a geological database based on borehole location has been created to model the deposit of Kalta area. The geological database in figure 5 shows the location of all boreholes present in the area base on their collar and survey file information. It is modeled on different in assay value, i.e., iron content present in the bore hole section.

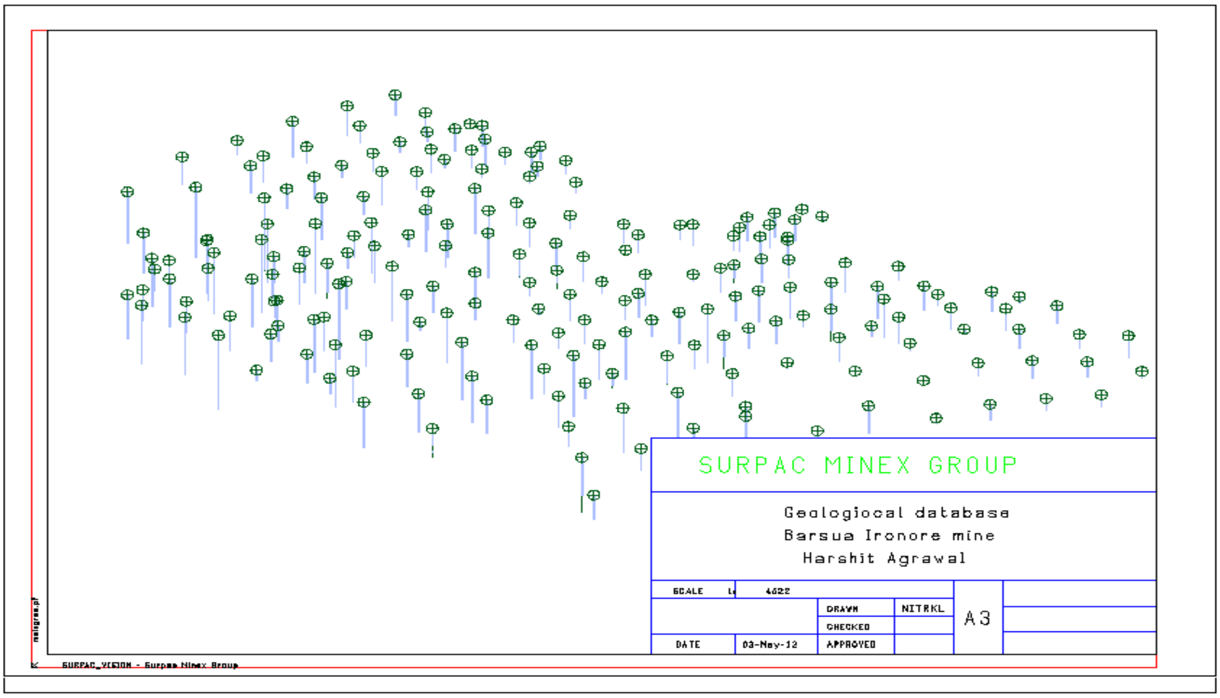

Figure 5: Geological database of borehole information of Kalta area.

The boreholes are sectioned in north-south direction at 100m interval and are digitized to form ore strings which are further concatenated to cover the entire deposit. The ore strings are shown in the following figure 6.

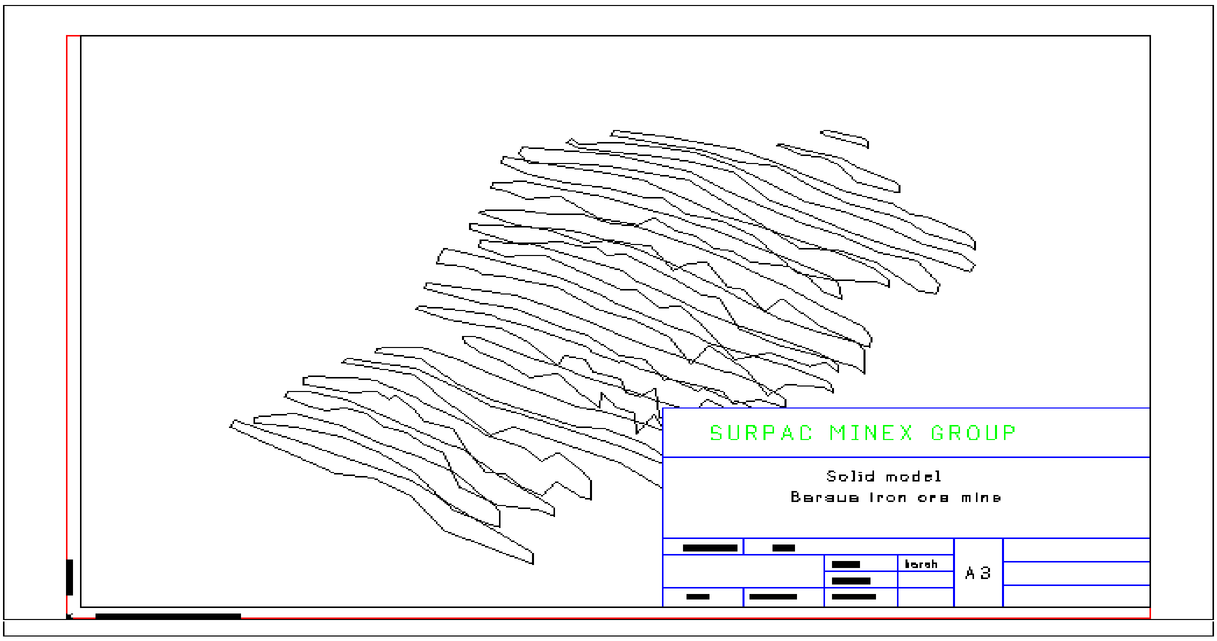

Figure 6: Ore string showing sections of the entire deposit.

Once the ore strings are made, it is composited to find basic statistics of the deposit to be able to make proper solid model and constraint block model and to determine reserve using ordinary kriging method. Several directional variogram have been drawn to find out the direction of anisotropy of the deposit, these variogram have been drawn at 0°, 45°, 90°, 135°, and -90° (vertically below). These variogram are used to find the major, semi- major and minor axis to carry out ordinary kriging in order to determine the reserve. Based on the composited data file obtained by compositing the borehole information at 5m composite and after analyzing them, following variogram were obtained. These variogram are shown in following figures (7-11).

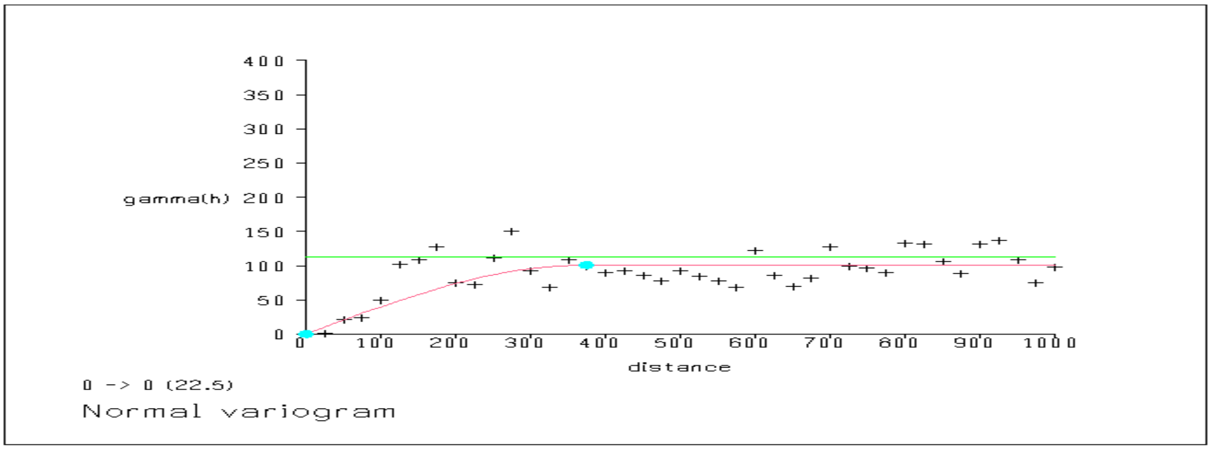

Figure 7: Normal variogram at 0° dip and 0° azimuth with 22.5° spread

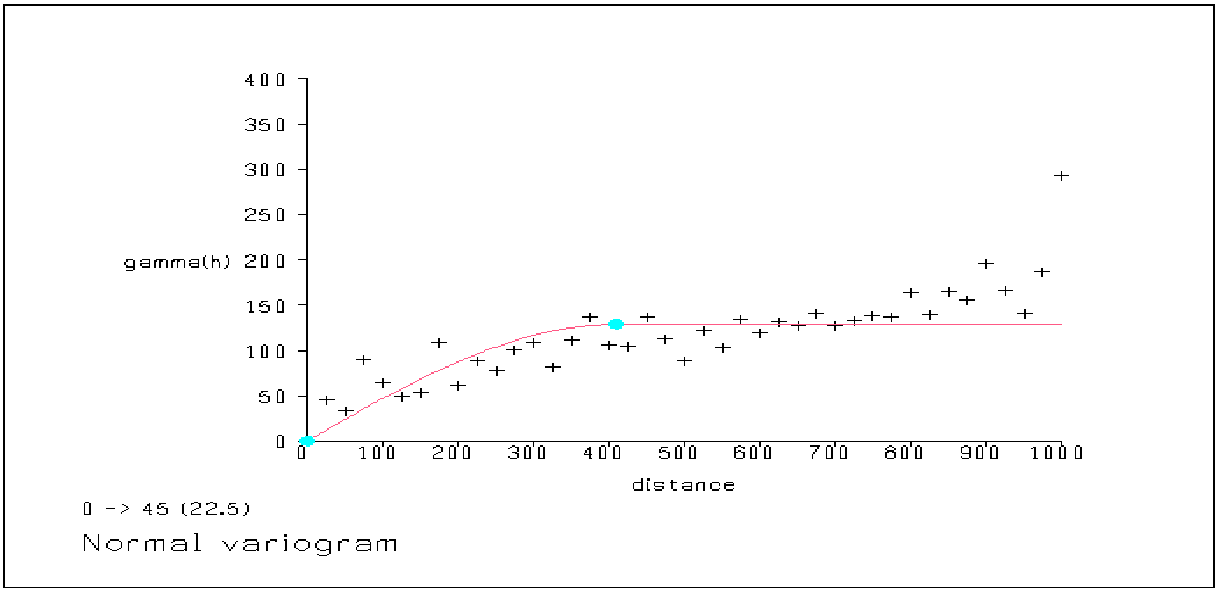

Figure 8: Normal variogram at 0° dip and 45° azimuth with 22.5° spread

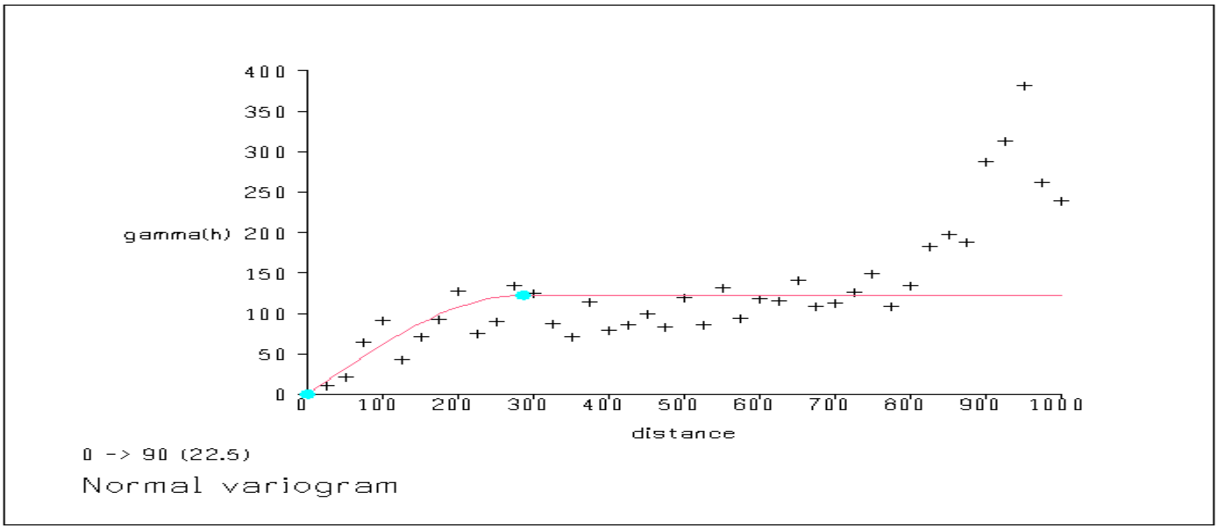

Figure 9: Normal variogram at 0° dip and 90° azimuth with 22.5° spread

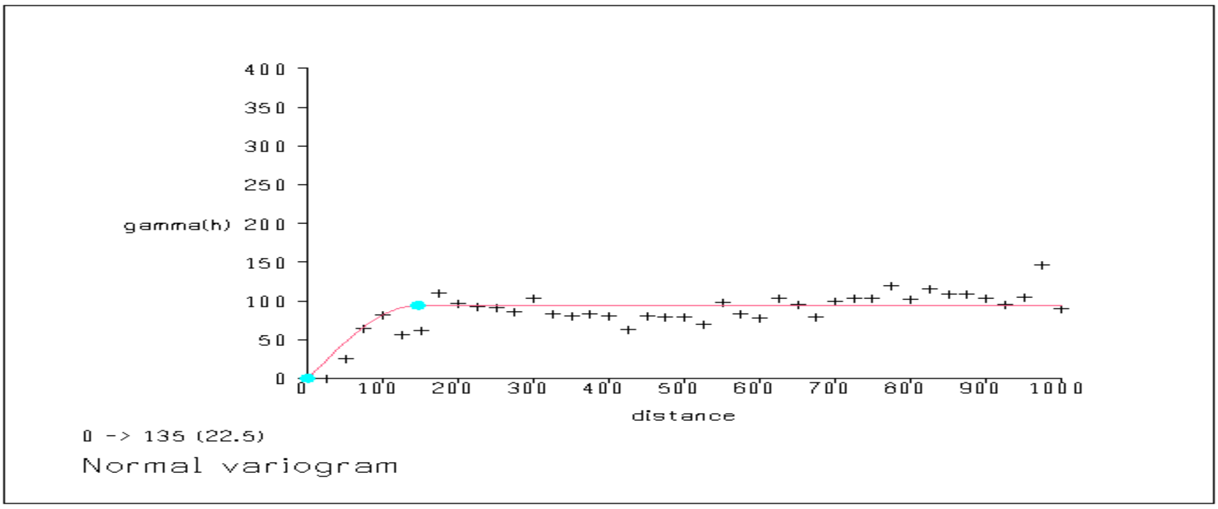

Figure 10: Normal variogram at 0° dip and 135° azimuth with 22.5° spread

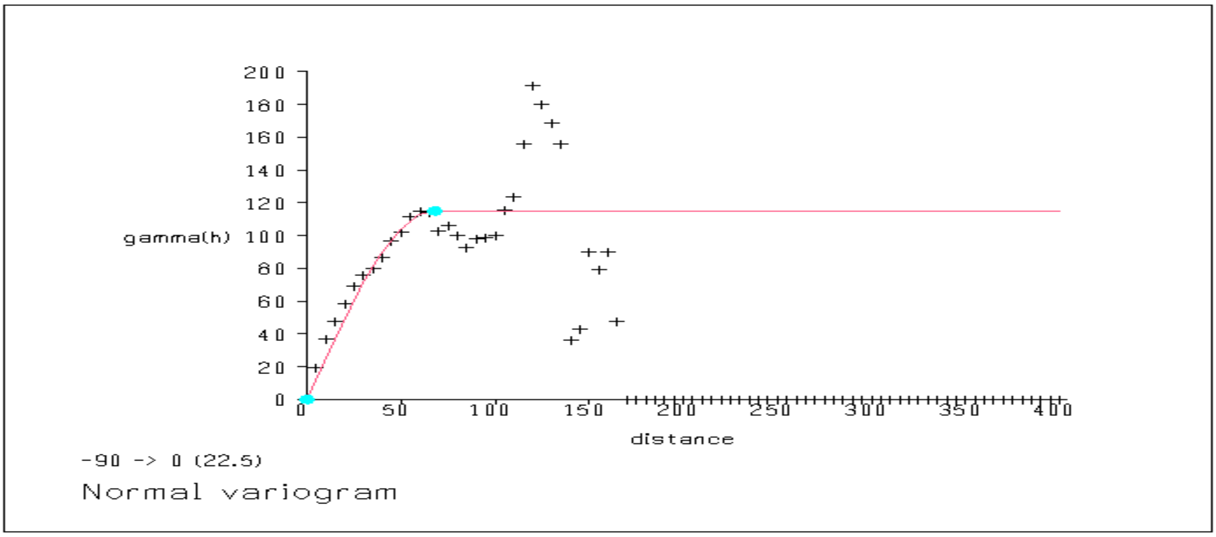

Figure 11: Normal variogram at -90° dip and 0° azimuth with 22.5° spread

The ore strings are oriented in clockwise direction and are then triangulated to form solid model of the deposit. The object after triangulation is validated for presence of edges, triangles, etc. Once validation is done then the objects are set to solid. The solid model thus obtained is shown in figure 12 below.

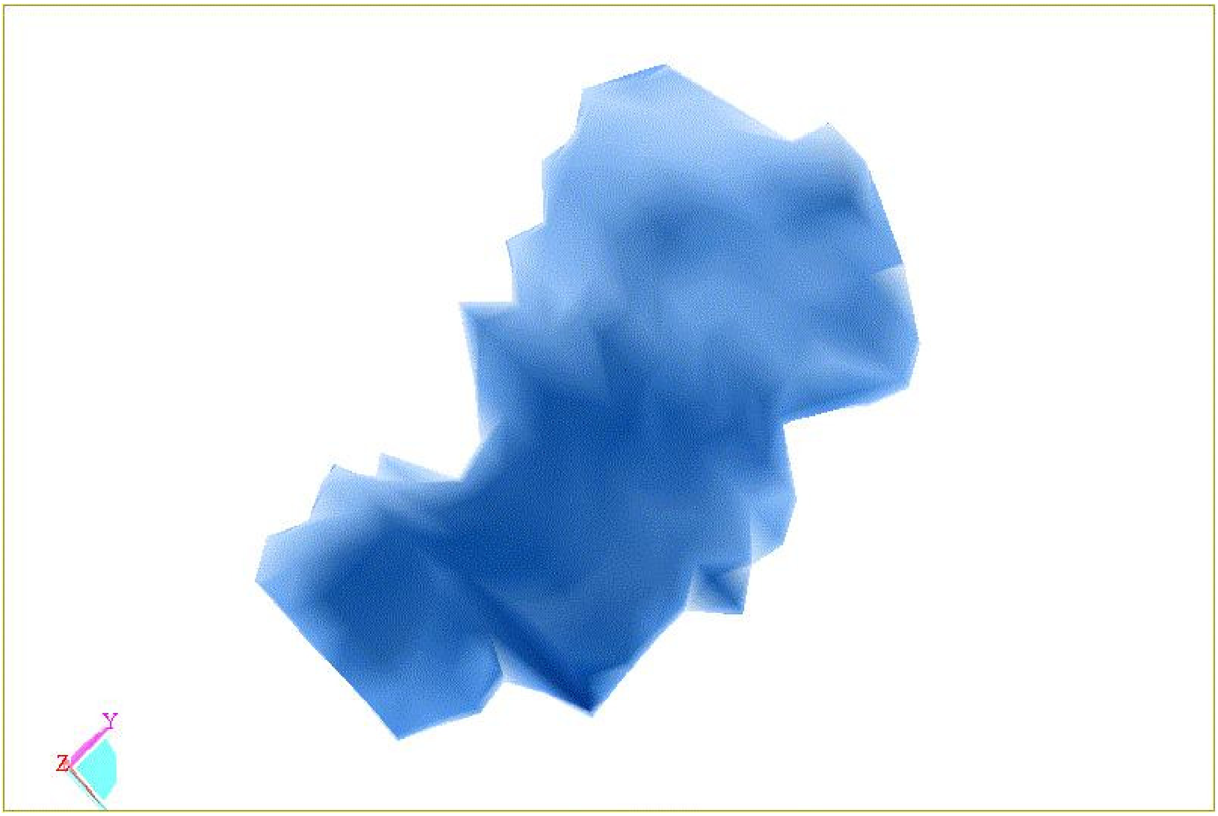

Figure 12: Solid model of the deposit.

The solid model so generated is incorporated in the block model of regular shape of 50m X 50m X 10m size to form the constraint block model. By incorporating the solid model to overall block model the extra blocks available in the area which are falling outside the ore deposit are removed so that better estimation of deposit can be done using ordinary kriging and the data generated are then used for pit sequencing. The constraint model thus obtained is shown in Figure 13. It shows upside down view of constraint model, to provide information about the variation in depth of the deposit, they are modeled as per cutoff grade of 50% iron ore content, 2% less than what the cutoff grade is actually being mined in the Barsua iron ore mine. .

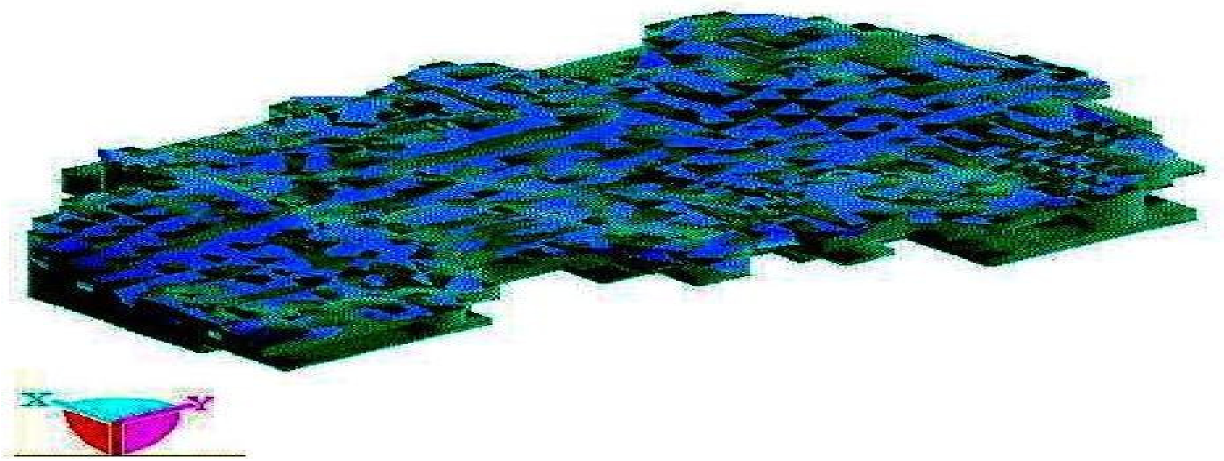

Figure 13: Constraint block model in upside down view showing extent of deposit.

4.1.2 Optimization using Minimum cut algorithm

Based on the ordinary kriging on the constraint model, 25900 blocks were found to be present within the deposit in constraint block model thus obtained, the data were then analyzed using Matlab to calculate the block economic value of the individual blocks, once the block economic values have been found, the minimum cut algorithm was used to calculate the blocks present in feasible ultimate pit giving maximum production. The minimum-cut algorithm returned 23563 values which were present in the ultimate pit layout. Production scheduling was then done to calculate yearly production target and hence the pit shape. The values so obtained, was modeled in SGeMS and the final pit layout is presented in following figure 14.

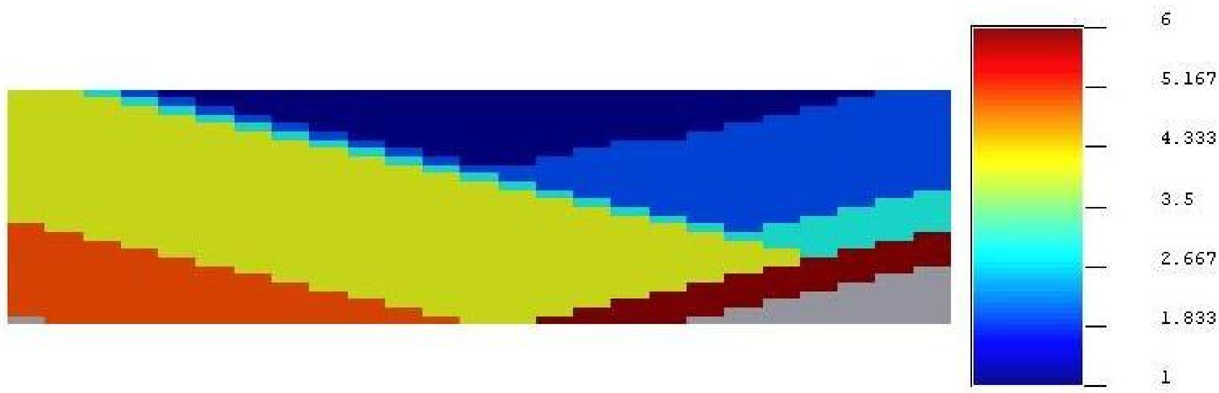

Figure 14: Vertical section of the pit layout.

In figure 14, the deep blue color shows the pit shape after first year, while light blue color show the shape of pit during second year, cyan color shows the shape of pit after second year and so on and so forth. The gray color shown, at the bottom right hand side show the waste blocks which are outside the ultimate pit limit and hence, will not be mined.

The discounted cash flow graph is obtained by analyzing the production at $160.68/ ton of iron ore. This value has been taken by averaging the last one year price of iron ore in international market (Source: http://www.indexmundi.com/commodities/commodityiron-ore). The discounted cash flow obtained at discounting rate of 10% is shown in figure 15.

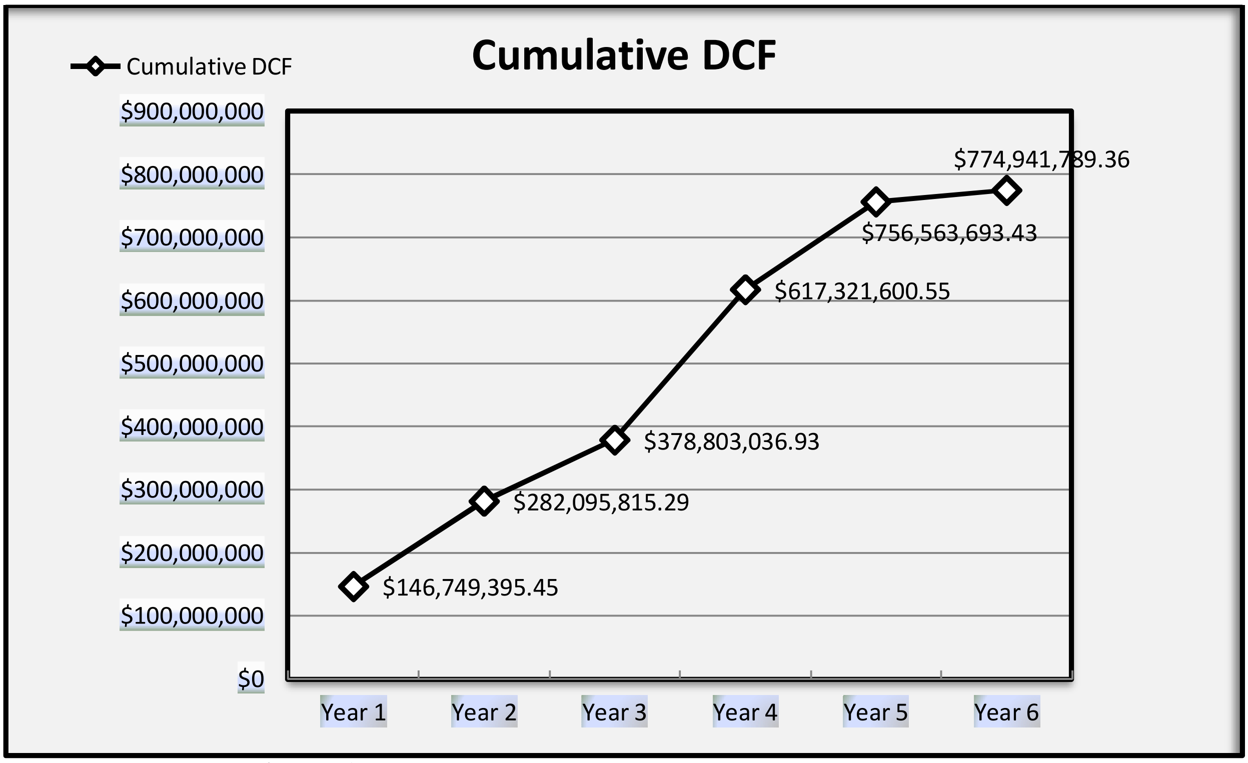

Figure 15: The discounted cash flow obtained for 6 years.

4.1.3 Generation of Algorithm

Taking analogy from the studies conducted by Bissiri 2003, algorithm for dynamic truck dispatch system is made. The algorithm is as follows:

Step 1: initialization of system with providing information on coordinates of faces, dump sites, crusher plant, instantaneous location of dumpers, number of working faces, total number of dumpers available, road condition factor, etc.

Step 2: Calculation of fixed distance d_i of working faces with the dump site and instantaneous distance d_{ij} of dumper j with respect to shovel i, cycle time of shovel, cycle time of dumpers, etc.

Step 3: Calculating the deviation of shovel from estimated production output using the formula stated in equation **3.**

Step 4: Calculation of shovel i stimulus to bid a dumper j. it is calculated from equation **4.**

Step 5: Calculating threshold of dumper j for shovel i, is given by equation **5.**

Step 6: Updating status of dumper, depending on whether dumper is loaded or empty.

Step 7: Calculating response function r_{ij} equation **1.**

Step 8: Allocation of dumper to shovel with maximum response value.

Step 9: Go to step 2.

Step 10: Stop.

The flow chart of the algorithm, in order to develop a C++ program for dynamic allocation of dumpers in open pit mining conditions has been illustrated in figure 16.

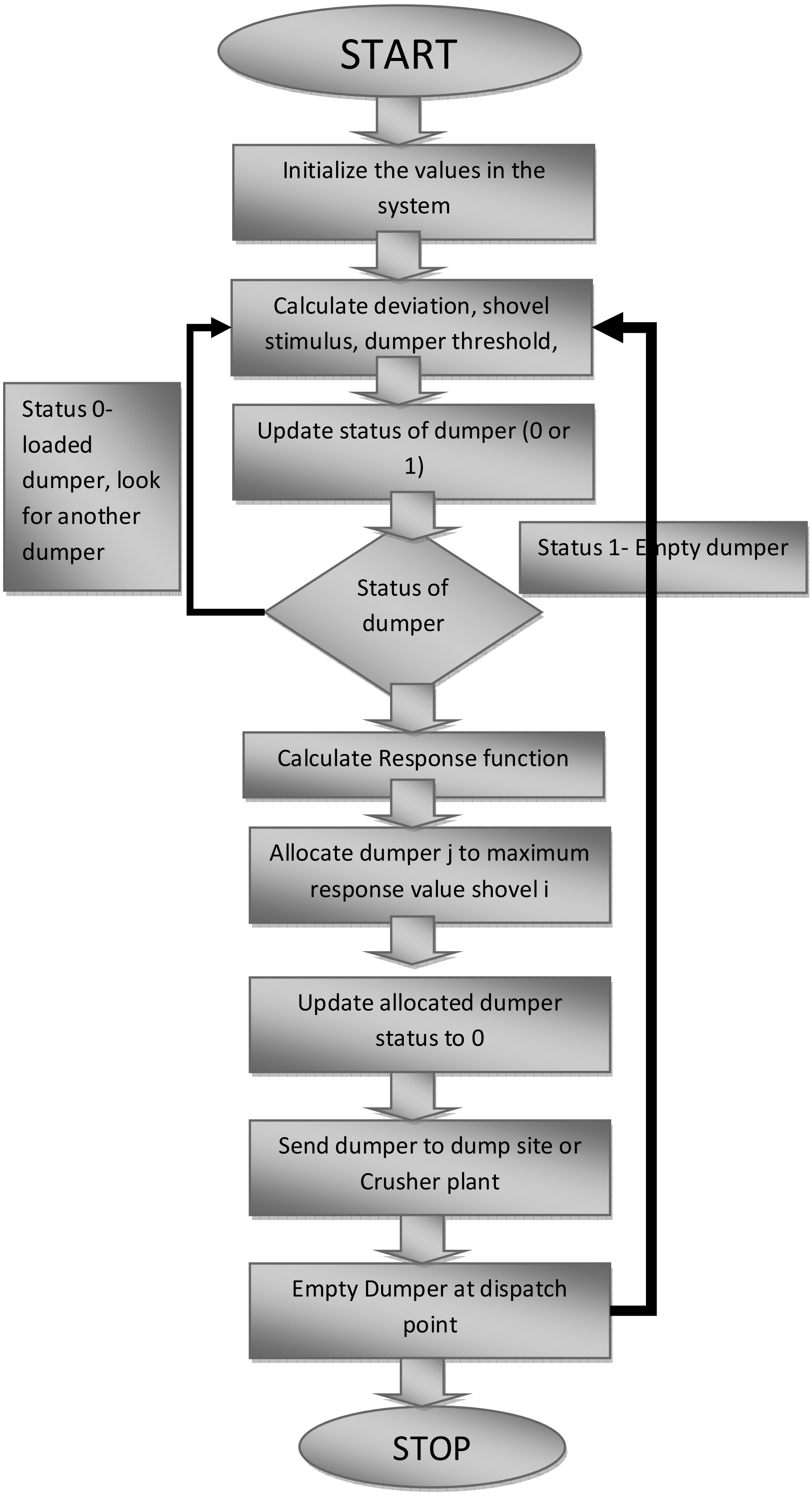

Figure16: Flowchart for generation of C++ program

CHAPTER- 5

CONCLUSIONS

Chapter- 5

Conclusion

5.0 Introduction

The ore body modeling is done using Surpac and the geological database, solid model and constraint block models was developed using Surpac. Owing to the flexibility, that Surpac data can be used in any other software a detail analysis of the constraint block model created in Surpac has been done in Matlab.

Using the block economic value code in Matlab the block economic value of each block in the constraint block model was calculated. To ensure slope stability of the pit, the blocks which are to be present in the ultimate pit is calculated using minimum cut algorithm code in Matlab. The ultimate optimized pit is determined by this code obeying slope constraint of 45^{o}.

The ultimate production scheduling code is used to determine the production schedule and thus top give yearly production target and shape of the pit i.e., number of blocks to be extracted in that time period.

The geo-statistical software SGeMS is used to plot the ultimate production scheduling in grid format to give 3D view of the pit and different color code gives different the indication when a particular block will be mines. This accounts for the long term planning.

The values obtained from the ultimate pit schedule can be used in C++ program developed using the algorithm provided earlier for defining location of working faces and thus overall distance to reach the dump and crusher site.etc will be done from the ultimate pit schedule data.

Using short range planning and day-to-day execution of the overall plan to reach the ultimate production target can be optimized by dynamically allocating the dumpers to the shovels based on real time monitoring data which can be obtained by using some real time monitoring programs or facilities like GPS navigation. These real time data are fed to the program/code which will dynamically allocate the shovel in order to minimize the shovel idle time and optimize production.

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